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# Research Note

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# RELATIONS BETWEEN INSIDE AND OUTSIDE BARK DIAMETER AT BREAST HEIGHT FOR DOUGLAS-FIR IN NORTHERN IDAHO AND NORTHWESTERN MONTANA[1].

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ABSTRACT

*Linear regression was used to predict breast high diameter inside bark from diameter outside bark for inland Douglas-fir. Observations were obtained from 777 trees, covering a wide range of sizes and ages, from northern Idaho and northwestern Montana. These predictions were compared to earlier studies of Douglas-fir bark thickness sampled in Washington, Oregon, and the northern Rocky Mountain region; similar results were obtained. Indirect estimates of bark growth are derived and implications for stand simulation modeling are discussed. Bark growth was estimated to comprise approximately 25 percent of total basal area growth for inland Douglas-fir.*

KEYWORDS: *Pseudotsuga menziesii*, bark thickness, bark growth, bark ratio, diameter inside bark estimation.

Estimates of inside bark diameter are often useful for determining the peeled wood volume of a tree. Preliminary results from a current study to model volume loss in top-killed trees (Monserud 1979) indicate that superior estimates of volume loss are obtained when a cylindrical form factor based on inside rather than outside bark diameter is used to estimate the parameter in the Behre hyperboloid described by Bruce (1972). Indirect estimates of bark thickness and bark growth also can be derived from the relations between inside and outside bark diameters.

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[1]The research reported here was financed in part by the USDA Expanded Douglas-fir Tussock Moth Research and Development Program.

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A specific need for estimated bark growth in stand simulation modeling was identified by Stage (1973) and Cole and Stage (1972). Because the diameter growth model they discussed only predicts wood growth, an estimate of future bark growth is needed to properly predict future diameter outside bark. Ignoring bark growth can lead to considerable bias in lengthy simulations, because predictions of wood growth will be based on an underestimate of outside bark diameter.

Interest may also be centered on obtaining estimates of past outside bark estimates (Johnson 1955, 1956; Spada 1960). The same procedures used to estimate future inside diameters can be used to predict past inside diameters--and usually more accurately, for the tree leaves a record of past inside bark wood growth.

This note presents breast height estimates of inside bark diameter, bark thickness, and the ratio of outside to inside bark basal area for inland Douglas-fir (*Pseudotsuga menziesii* var. *glauca* [Mirb.] Franco) growing in the Northern Rocky Mountains of Idaho and Montana.

## METHODS

Measurements were obtained from 141 plots (fig. 1) located in seven national forests in northern Idaho and northwestern Montana (Kaniksu, Coeur d'Alene, St. Joe, Clearwater, and Nezperce in Idaho and Kootenai and Lolo in Montana). The plots were established in the summer and fall of 1976 to provide stem analysis data for a site index and height growth study for inland Douglas-fir (Monserud 1978). A total of 777 trees were measured, with a range in outside bark diameter at breast height (DOB) of 0.6 to 41.9 inches (1.5 cm to 106.4 cm).

### Field Procedure

1. Plots were selected to cover a wide range of slopes, aspects, elevations, and habitat types. Suitable site trees were the three largest healthy dominant trees on an approximately 1/2-acre plot that was representative of the growing conditions in the stand. Site trees could have no sign of early suppression or damage, judging from increment cores. Three additional Douglas-fir from the nondominant crown classes were measured on each plot.

2. The selected trees were measured to the nearest 0.1 inch (0.25 cm) for diameter outside bark at breast height (4.5 ft; 1.37 m) using a diameter tape.

3. The selected trees were then felled and sectioned at breast height. Two inside bark diameter measurements were made: the largest diameter ($DIB_1$) and the perpendicular diameter ($DIB_2$) were measured to the nearest 0.1 inch (0.25 cm).

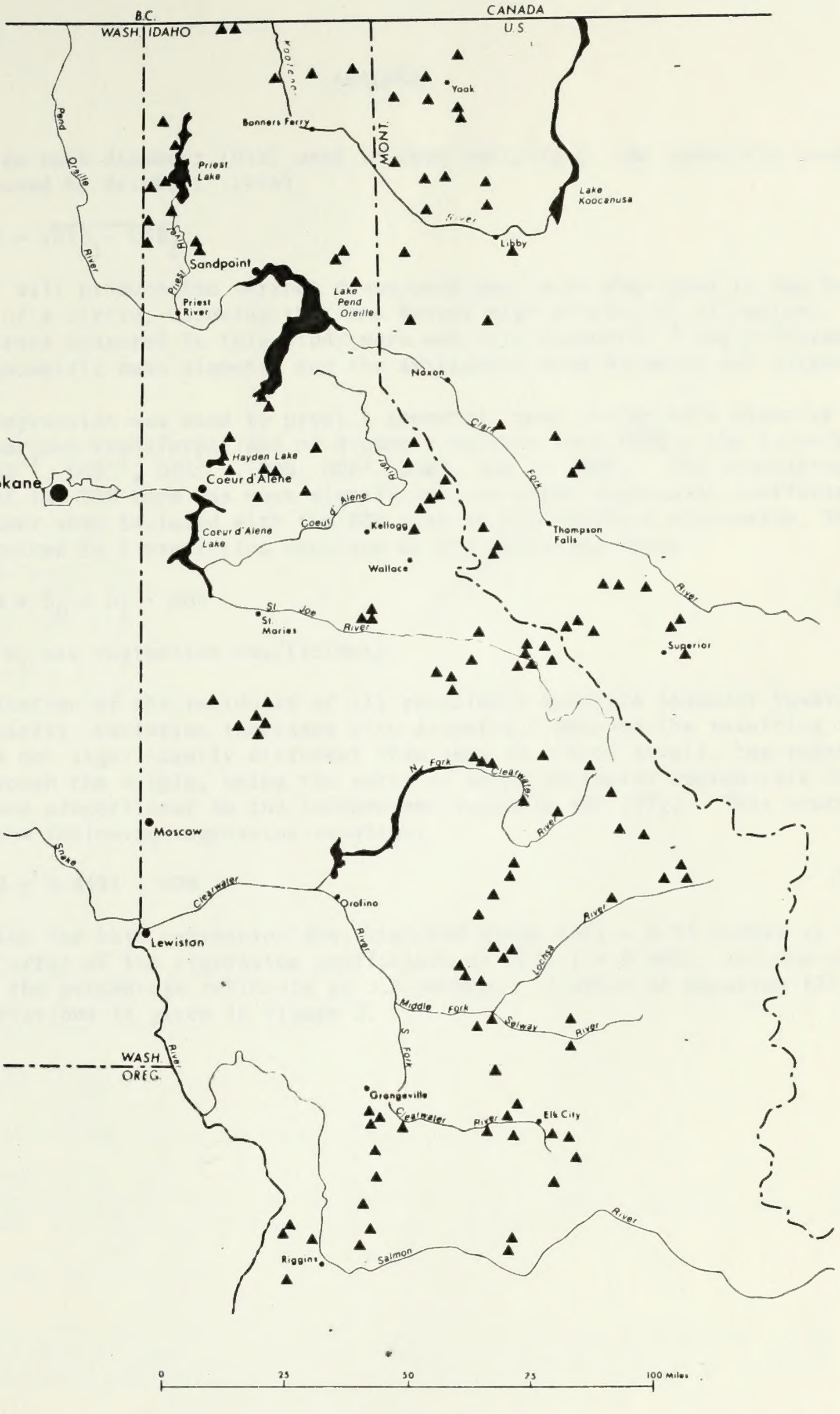


Figure 1.--Douglas-fir site index study plot locations.

## ANALYSIS

The inside bark diameter (DIB) used in this analysis is the geometric mean diameter proposed by Brickell (1976):

$$DIB = \sqrt{DIB_1 \cdot DIB_2}$$

This diameter will produce the correct cross-sectional area when used in the formula for the area of a circle, assuming that the breast high section is elliptical. Because the trees measured in this study were not very eccentric,[3] the difference between the geometric mean diameter and the arithmetic mean diameter was slight.

Linear regression was used to predict geometric mean inside bark diameter as a function of various transformations of diameter outside bark (DOB); the transformations used were: $DOB^{-2}$, $DOB^{-1}$, $DOB^{1/2}$, DOB, $DOB^2$, $DOB^3$, and ln (DOB). The regression coefficient of the DOB term was most significant; no other regression coefficients were significant when included with the DOB term in the multiple regression. This procedure resulted in a prediction equation of the following form:

$$DIB = b_0 + b_1 \cdot DOB \tag{1}$$

where $b_0$ and $b_1$ are regression coefficients.

An examination of the residuals of (1) revealed a moderate tendency towards heteroscadisticity: variation increased with diameter. Because the resulting intercept term ($b_0$) was not significantly different than zero ($\alpha$ = 0.05 level), the regression was refit through the origin, using the ratio of means estimator appropriate for data having variance proportional to the independent variable (Ek 1971). This procedure resulted in the following regression equation:

$$DIB = 0.8694 \cdot DOB \tag{2}$$

Statistics for this regression are: standard error (SE) = 0.53 inches (1.35 cm), the standard error of the regression coefficient is $SE(b_1)$ = 0.0022, and the standard deviation of the percentage residuals is 3.5 percent. A graph of equation (2) and the 777 observations is given in figure 2.

[3]The ratio of $DIB_2$ to $DIB_1$ had an average value of 0.946 with a standard deviation of 0.04.

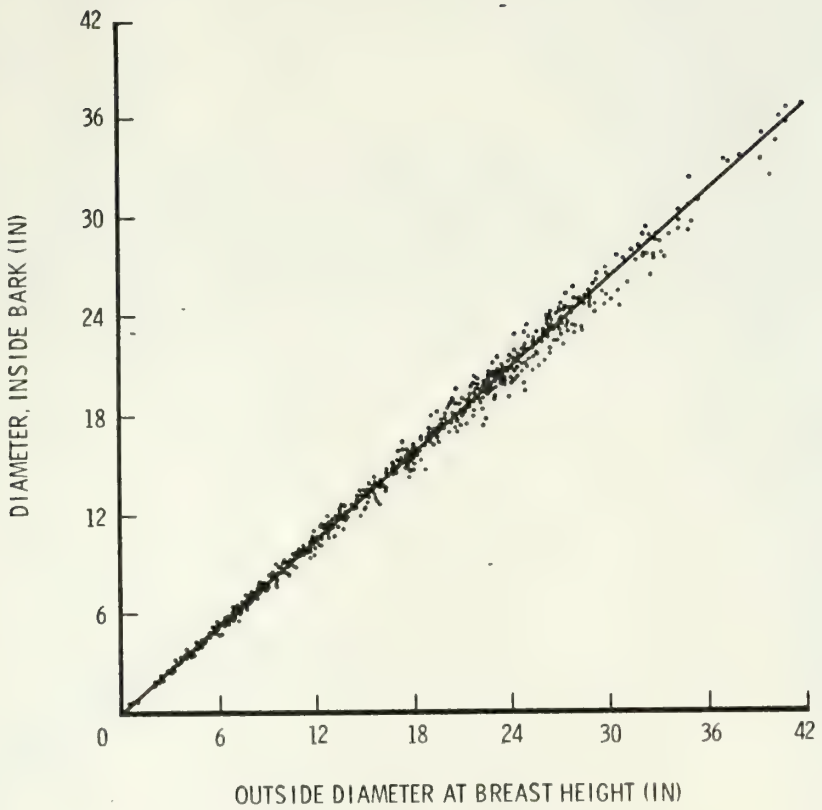


Figure 2.--Inside vs. outside bark diameter at breast height for 777 observations of inland Douglas-fir in northern Idaho and northwestern Montana. Regression equation (2) is plotted as a solid line.

## DISCUSSION

### Double Bark Thickness

Because double bark thickness (BARK) is simply the difference between the outside and inside bark diameters, the parameters in equation (1) can be transformed to allow for estimating bark thickness directly:

$$\text{BARK} = -b_0 + (1-b_1) \cdot \text{DOB} \qquad (3)$$

where $b_0$, $b_1$, and DOB are as defined in equation (1).

When the slope estimate given in equation (2) is used in equation (3) with the assumption that $b_0 = 0$, the following equation results:

$$\text{BARK} = 0.1306 \cdot \text{DOB} \qquad (4)$$

Using equation (4) allows the results of this study to be compared to earlier studies of Douglas-fir bark thickness in eastern Washington and Oregon and in the Northern Rocky Mountain Region.

Spada (1960) reports on a sample of 2259 inland Douglas-fir from the east side of the Cascade Range. His equation for bark thickness was:

$$\text{BARK} = 0.0704 + 0.1176 \cdot \text{DOB} \qquad (5)$$

Johnson (1955) sampled 527 coastal Douglas-fir (*P. menziesii* var. *menziesii*) on the west side of the Cascade Range and obtained the following bark thickness equations:

$$\text{BARK} = \begin{cases} -0.60 + 0.154 \cdot \text{DOB} & \text{if DOB} \geq 10.0 \\ 0.0 + 0.094 \cdot \text{DOB} & \text{if DOB} < 10.0 \end{cases} \tag{6}$$

Graphs of equations (4) through (6) and the observations used in the current study are all given in figure 3. It is apparent that the slope for the northern Idaho dataset (0.1306) is intermediate between the slopes for the west and east sides of the Cascades (0.154 and 0.1176, respectively). It is also apparent that little difference exists between the results of these three studies, when viewed in relation to the natural variation in bark thickness.

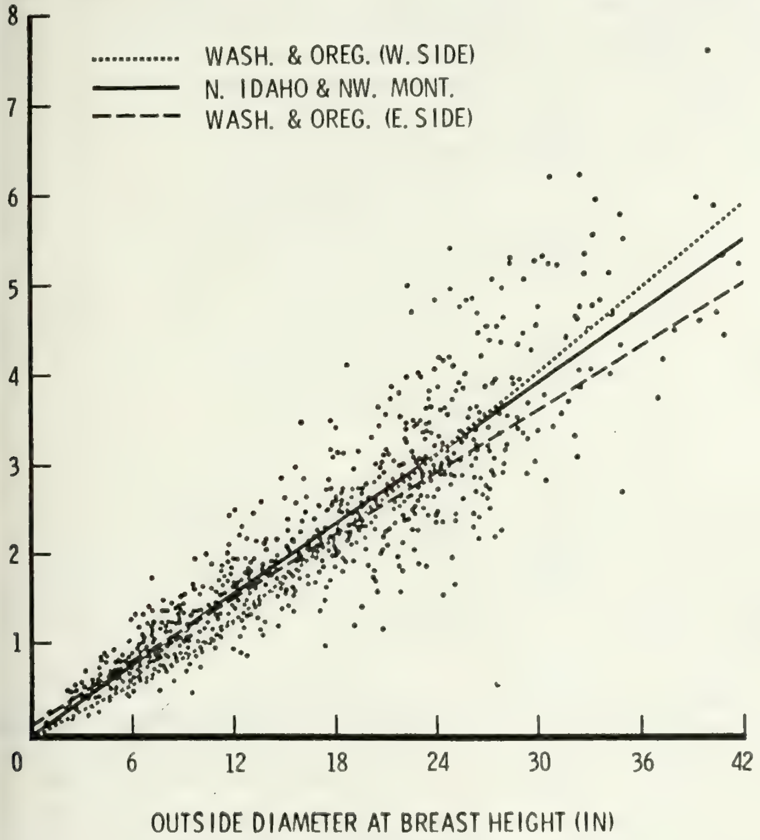


Figure 3.--Double bark thickness vs. outside bark diameter at breast height for 777 observations of inland Douglas-fir in northern Idaho and northwestern Montana. Bark thickness equations (5) and (6) are plotted with equation (4) to allow for comparison with results from Washington and Oregon.

Finch (1948) reports on a study of bark thickness for 12 species growing in the Northern Rocky Mountain Region. Based on a limited sample of 156 observations of inland Douglas-fir, Finch provides an estimate of bark growth that can be transformed into the following relationship:

$$\text{BARK} = 0.134 \cdot \text{DOB} \tag{7}$$

This estimate agrees almost exactly with the results obtained in the current study (equation 4), which was based on observations from the same geographic area.

## Basal Area Ratio

Cole and Stage (1972, p. 8) point out that the ratio of $DOB^2$ to $DIB^2$ (termed BAR, basal area ratio) is needed to properly predict future diameter outside bark from present diameter outside bark and estimated area of wood growth (inside bark). Using the 777 Douglas-fir observations, the average of this basal area ratio is:

$$BAR = DOB^2/DIB^2 = 1.3306 \qquad (8)$$

The standard deviation is 0.095. BAR vs. diameter outside bark is plotted in figure 4.

An attempt to explain some of the residual variation in BAR proved fruitless. Using tree characteristics (age, height, crown ratio, basal area percentile), site characteristics (slope, aspect, elevation, habitat type, site index), and stand density measures (basal area per acre, crown competition factor), at most 2 percent of the residual variation was explained by any variable.[4]

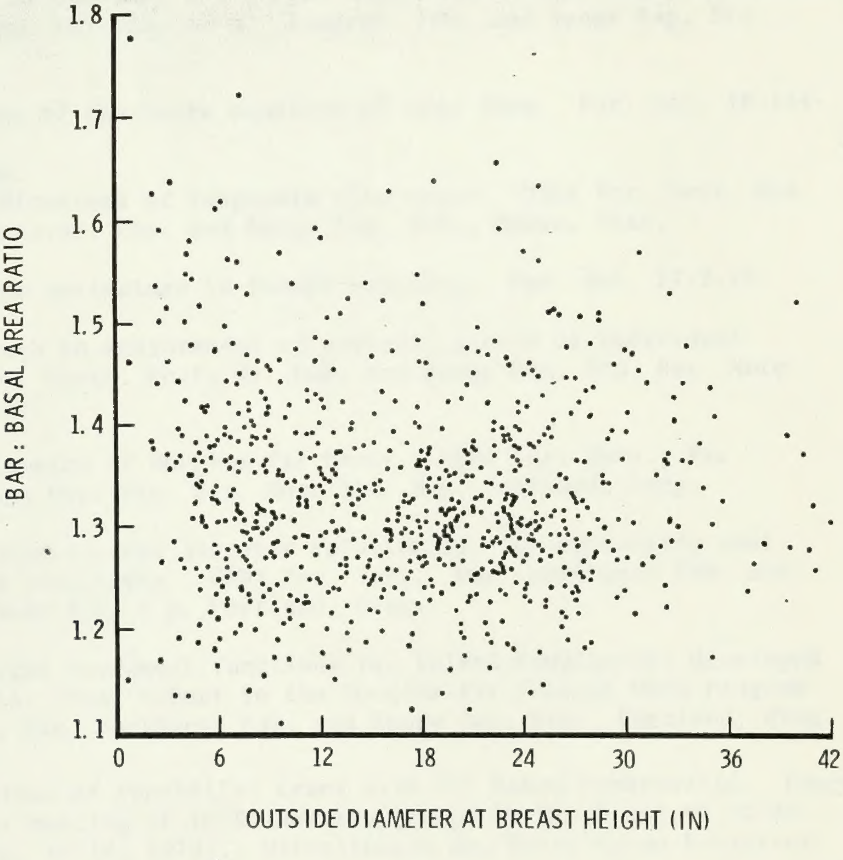


Figure 4.--Ratio of outside to inside bark basal areas (BAR) vs. outside bark diameter for 777 observations of Inland Douglas-fir. BAR has an average of 1.3306 and a standard deviation of 0.095.

## Bark Growth

Bark growth is an extremely difficult variable to measure. Indirect estimates can be obtained, however, using the relationships between inside and outside bark diameters and the measured wood growth. Indeed, Johnson (1955, 1956), Spada (1960), and Finch (1948) emphasize obtaining an estimate of bark growth so that an accurate estimate of past diameters (outside bark) can be obtained.

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[4]Similar results were obtained when this same set of potential predictor variables was used to reduce the residual variation in equation (2).

Because BAR-1.0 is the corresponding estimate of bark basal area growth as a percent of wood basal area growth, it is apparent from equation (8) that bark growth is approximately one-third of wood growth for Douglas-fir, and one-fourth of total basal area growth. To paraphrase Johnson (1956), if bark growth is ignored in estimating future (or past) outside bark diameters, the resulting bias would be appreciable.

The preceding estimate of bark growth is valid only if the ratio of outside to inside bark basal area does not vary with time. Based on the rather weak relationship between BAR and tree age (2 percent of the residual variation in BAR was explained by age), this study did not provide evidence that BAR did vary over time. Of course, repeat measurements on the same trees over time would be necessary to properly examine this question, and such information was not obtainable in this study.

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